Energize Missouri: Algae-Based Renewable Energy Study

Tasks E and F
Algae-Based Biodiesel Challenges and Recommendations

Final Report

For
Missouri Technology Corporation

MRIGlobal Project No. 110754.1-E and F

August 8, 2011

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This project was supported by DOE Award No. DEFG2609EE0000131

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MRIGlobal Project No. 110754.1-E and F

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Preface

This report was prepared for the Missouri Technology Corporation under a subgrant award to MRIGlobal, and entitled “Energize Missouri: Algae-Based Renewable Energy Study” signed by Mr. Jason Hall and dated February 28, 2011. Work was initiated in accordance with a work plan submitted and approved on March 11, 2011. The project team includes members from MRIGlobal, Washington University in Saint Louis, and the University of Missouri, Columbia.

The objective of the grant is to produce a study to help define the development and commercialization of algae as a fuel source that would be a valuable adjunct to the state energy plan. The study would emphasize the potential benefits to the state economy that a commercial algae industry could bring, opportunities for Missouri to become a leader in such an industry, and the policy steps and collaborations that the state could initiate to strengthen Missouri’s leadership in this area. The study is divided into seven tasks plus a final report. This report is the result of Tasks E and F, which sought to identify technical, market, and regulatory challenges that prevent or hinder broad implementation of algae-based bio-fuel growth, harvesting, and production systems. In addition, it recommends strategic policy initiatives that Missouri could pursue to advance the large-scale implementation of algae-based bio-fuel systems.

This Tasks E and F study was authored by Bill Babiuch, Director of Energy Sector Planning and Analysis at MRIGlobal. The author wishes to acknowledge contributions of Thomas Grant, Stan Bull, Amber Noll, Jeffrey Withum, Greg Karr, Jacob Aspinwall, and Josh Campbell.

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Section 1. Innovation Challenges of Algae-Based Renewable Energy

1.1 Technological Innovation

The large-scale market penetration of technological innovations, like algae-based biodiesel fuel, is a low-percentage game. Yet, there is almost universal agreement that innovation is critical to economic growth. This in short is the *innovation paradox*. Figure 1 depicts the percentage of projects that will make it from the research stage to product development and market entry. Based on a review of available data in the literature, only about 2 out of every 100 research ideas like, "producing biodiesel from algae," make it into the marketplace. Even with the low-probability of research ideas succeeding, the public and private sectors invested a combined $398 billion in scientific research and technology development in 2008 (National Science Board, 2010), because technological progress is a key element of economic growth. Paul Krugman aptly explained this link between innovation and economic productivity when he wrote:

> [E]conomic expansion represents the sum of two sources of growth. On the one side are increases in "inputs," growth in employment, in the education level of workers, and in the stock of physical capital (machines, buildings, roads, and so on). On the other side are increases in the output per unit of input; such increases may result in better management or better economic policy, but in the long run are primarily due to increases in knowledge...[O]ne arrives at a crucial insight about the process of economic growth; sustained growth in a nation's per capita income can only occur if there is a rise in output *per unit of input*…How, then have today's advanced nations been able to achieve sustained growth in per capital income over the past 150 years? The answer is that technological advances have led to a continual increase in total factor productivity—a continual rise in national income for each unit of input. In a famous estimate, MIT Professor Robert Solow, concluded that technological progress accounted for 80 percent of the long-term rise in U.S. per capita income, with increased investment in capital explaining only the remaining 20 percent (Krugman, 1994 pp. 67-68).

While Solow's pioneering study (1957) established that technological innovation is a key contributor to economic growth, along with traditional economic variables such as capital and labor, there is an ongoing debate among economists and policymakers about the magnitude of the impact of innovation on the economy, primarily due to the challenges of measuring innovation and collecting reliable innovation data.[1] In other words, most people believe technological innovation is critical to a nation's economic growth, but it is very difficult to prove the link due to the challenges of measuring innovation. This puts research organizations in a

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[1] See Dale Jorgensen's *The Economics of Productivity* and the report by the Advisory Committee on Measuring Innovation in the 21st Century Economy for an in-depth analysis on this topic.

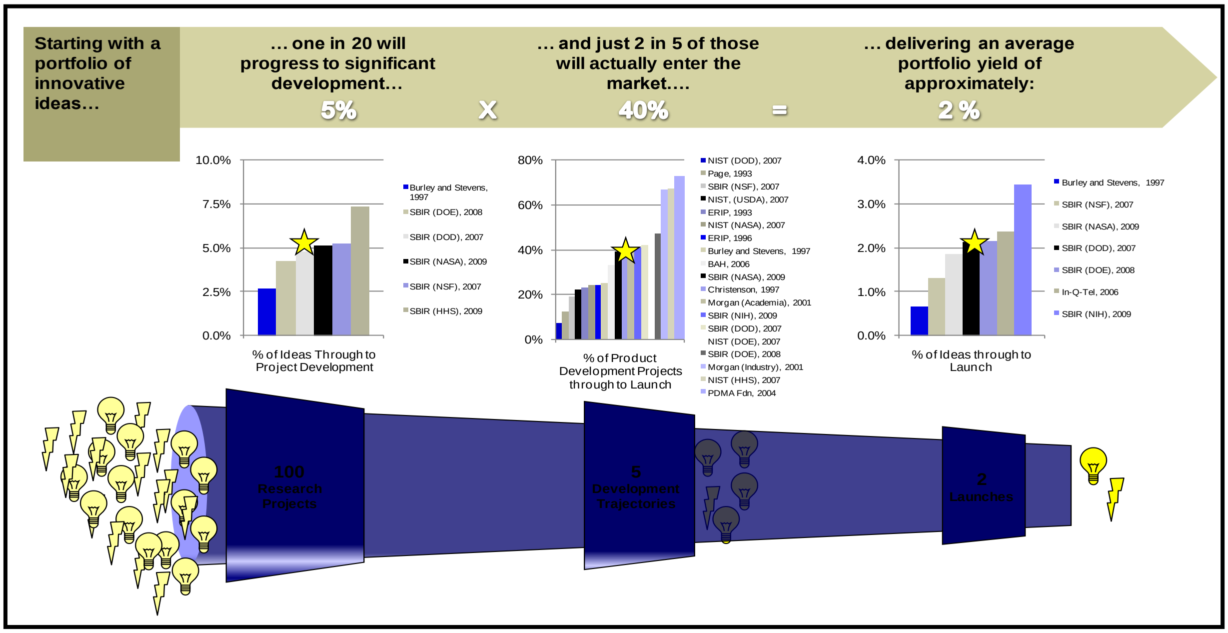

Figure 1. Decay Curve From Ideation to Market Entry
From Unpublished Booz Allen Hamilton/MRIGlobal Study

difficult position when they have to "defend" their activities to government officials or corporate boards by placing an economic value on their work.

1.2 Innovation Forces[2]

The commercial success of an innovation is influenced by three interactive forces (1) science and technology (S&T), (2) markets, and (3) policy. The forces of progress in S&T affect the ability of entrepreneurs to introduce new products and processes to the marketplace. While forces within the marketplace impact the speed and scale at which an innovation penetrates its target market (Kline and Rosenberg: 1986). In other words, even if a technological breakthrough enables you to commercialize a better mousetrap, you won't sell it if the consumer doesn't have a mouse problem, or they do not want to pay the extra cost for the new mousetrap, because their needs were being met with the existing, less expensive model. Conversely, there may be a consumer demand for a product or service that is beyond the reach of the existing S&T, or relies on advanced technology that will only penetrate a niche market that can bear the cost for the premium product or service. As a general rule, the dovetailing of market needs with S&T advances is critical for the large-scale market penetration of an innovation. When this does not occur, policy may be enacted to adjust for S&T or market deficiencies through technology push or market pull mechanisms, such as support for technology R&D or tax incentives to bring down the consumer costs of new technologies. (**NOTE:** Policy options to help "push" algae technology, and "pull" it into the liquid fuels market are discussed in the Recommendations section of this report.)

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[2] See *Common Factors Behind Success and Failure of Algae Innovations* by Paluszkiewicz and Mak for an in-depth review of theoretical frameworks for understanding the factors influencing the successful adoption of innovations.

An array of state and Federal policies has been enacted in the past decade to spur the development of a biofuels industry in the United States and encourage consumers to purchase alternative fuel vehicles (AFVs).[3] Analysis of the role of public policies in fostering the market penetration of biodiesel fuels in Europe, which consumes much more biodiesel than the U.S., supports the notion that policies can play a key role in adjusting S&T and market deficiencies to positively impact the commercial deployment of biodiesel.[4] While less biodiesel is produced in the United States than Europe, studies have demonstrated that government policy has also played a key role in the market penetration of biodiesel in the liquid fuels market, particularly the biodiesel tax credits and volume mandates in the Renewable Fuel Standard (RFS) (**NOTE:** These policies are discussed in more detail in the Regulatory Challenges section below).

When discussing the commercial success of new technologies, it is important to highlight that if one or more of these three interactive forces is "out of sync," the innovation is unlikely to successfully penetrate the mainstream market. For instance, in the case of algae, there was a strong desire by the coal industry for algae production to play a role in carbon dioxide (CO_2) mitigation (i.e., market force) several years ago—as noted in Task D. However, the interest and investment of the coal industry proved to be short lived because (1) algae S&T was years away from enabling algae farms to operate at a scale necessary to serve as the target market for CO_2 produced at coal-fired power plants given the magnitude of power plant emissions; and (2) climate change policy was not enacted at the Federal level, thus there was no regulatory driver to motivate power plant operators to reduce their CO_2 emissions.[5]

1.3 The Innovation Process

Before discussing the S&T, market, and regulatory, challenges impacting algae-based renewable energy, it is important to review the stages in the innovation process to provide a common frame of references when we talk about a technology moving from the idea stage to the marketplace. Economic theories about the process of technological innovation can be traced to Joseph Schumpeter's concept of "creative destruction," and the process by which new ideas and products enter the marketplace (Schumpeter, 1942). The stages presented below are intended to be representative of the agreed-upon major stages of innovation in the literature and draw heavily upon definitions developed by the Environmental Protection Agency (EPA) and the National Science Board (NSB).[6]

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[3] For an in-depth review of these policies, see Randy Schnepf's "Agriculture-Based Biofuels: Overview and Emerging Issues." Congressional Research Service, January 24, 2011; and Brent Yacobucci's "The Market for Biomass-Based Diesel Fuel in the Renewable Fuel Standard." Congressional Research Service, February 11, 2011. For a comprehensive list of state and Federal biofuel policies, go to the Database of State Incentives for Renewable Energy (DSIRE) at http://www.dsireusa.org/.

[4] See "Part 2—Biodiesel Around the World" in Greg Pahl's *Biodiesel: Growing a New Energy Economy* for a detailed look at the role of public policy in the diffusion of biodiesel in other countries.

[5] See "The Synergy of Coal and Microalgae" for more background on the coal-algae relationship in *A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae—A Closeout Report.*

[6] See EPA's Research and Design Continuum Website, http://www.epa.gov/etop/continuum.html and NSB's "Definitions of R&D," contained in *Science and Engineering Indicators 2010*, Chapter 4, page 8 http://www.nsf.gov/statistics/seind10/pdf/c04.pdf.

- The first stage is ***research***, which strives to gain more knowledge or understanding about a subject under study. Research is often classified as either "basic research," which is the search for knowledge without specific applications in mind, or "applied research," which strives to gain knowledge or understanding to meet a specific, recognized need.
- The second stage is ***development***, which is the systematic use of scientific knowledge, and/or insights derived from existing phenomena, that are often a result of learning by doing, toward the production of useful materials, devices, systems, or methods, including their design and development.
- The third stage is ***demonstration***, which may be pilot or commercial scale, to show the technology's range of performance, optimize its operational parameters, and better understand its cost parameters. Substantial redesign and debugging may take place in the demonstration phase until final robustness and optimization can be established. Findings from this stage may be used to market the innovation to financial backers and potential customers. In this report, the acronym RD&D, is used to refer to the research, development and demonstration stages of innovation.
- The fourth and final stage is the ***diffusion*** of the innovation into the marketplace, which involves the implementation of a business plan for the innovation. This stage encourages the adoption or purchase of an innovation through the flow of information about the technology within the target market, and by removing barriers to the innovation's implementation.

The diffusion stage is worth exploring further because it is within this stage that an innovation's market success, or the lack thereof, is determined. Rogers' classic diffusion curve begins with a commercial innovation initially being adopted by the innovators, followed by the early adopters, the early and later majorities, and finally the laggards (Rogers, 1995). Rogers' diffusion curve was the basis for what is commonly referred to in the innovation literature as the "S-Curve," or "Bell Curve" (See Figure 2).

Several decades after Rogers released *Diffusion of Innovations*, Geoffrey Moore published *Crossing the Chasm*, which took exception with the notion that technology diffusion involved a "continuity in stages corresponding to the psychological and social profile of various segments," (Moore, 2009, p. 13, HarperCollins e-books. Kindle Edition).[7] Instead of the diffusion of a new technology being a smooth process akin to passing the baton in the relay from one participant to the next, Moore contends that there are gaps between the consumer groups, and "[e]ach of these gaps represents an opportunity for marketing to lose momentum, to miss the transition to the next segment, thereby never to gain the promised land of profit-margin leadership in the middle of the bell curve (Moore, 2009, p. 16, HarperCollins e-books. Kindle Edition)." While there are gaps throughout the diffusion segments, Moore maintains that the critical point in an innovation's diffusion is moving from early adopters to the early majority (or from visionaries to pragmatists, in Moore's terminology) (see Figure 2). Moore contends that "this chasm, between the early adopters and the early majority, represents a pattern in market development that is based on the

[7] Moore goes on to note: "What is dazzling about this concept (i.e., the bell-shaped S-curve) is its promise of virtual monopoly over a major new market development. If you can get there first, "catch the curve," and ride it up through the early majority segment, thereby establishing the de factor standard, you can get rich very quickly, and "own" a highly profitable market for very long time to come" (Moore, 2009, p. 14).

tendency of pragmatic people to adopt new technology when they see other people like them doing the same. This causes them to hang together as a group, and the group's initial reaction…is to hesitate and watch. This is the *chasm effect*" (Moore, 2009, Preface. HarperCollins e-books. Kindle Edition).

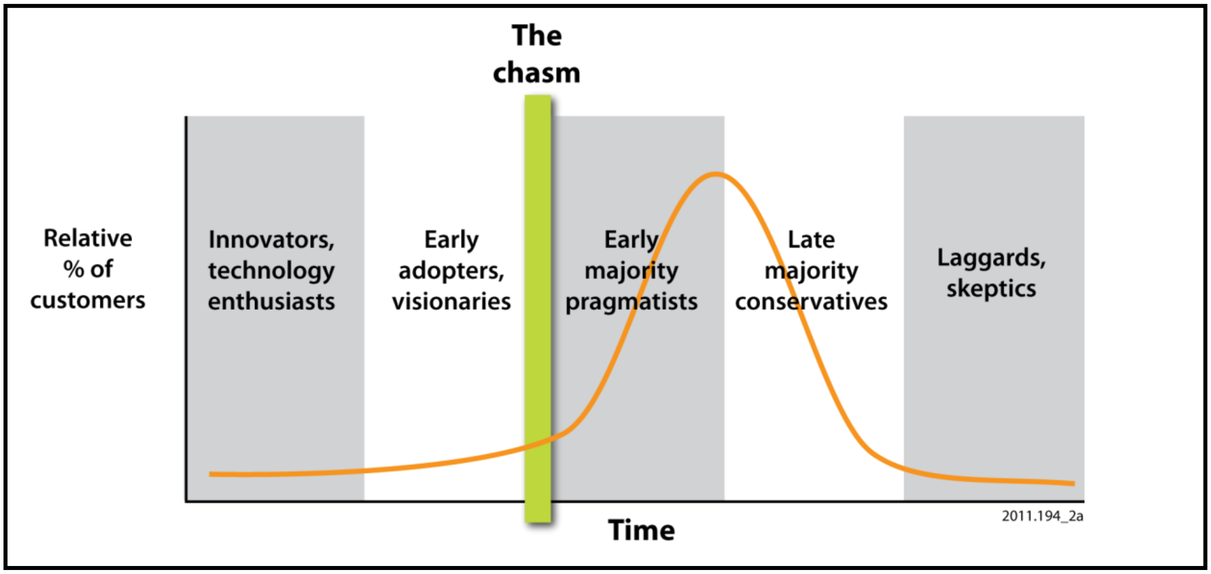

Figure 2. Adoption of Rodgers' Diffusion Curve to Chasm Model
Based on Diagram Published in "Closing the Chasm" by Doc Searls

In other words, uncertainty about a new technology is reduced among the consumers comprising the early majority by members of that group looking to others in their category to gain the reassurance to adopt the innovation. This is akin to large freight company deciding to change over to a new liquid fuel, such as algae-based biodiesel, after it has seen a competing freight company successfully use the fuel, thereby confirming that it "works as advertised" by the enthusiasts and visionaries.

1.4 Algae's "Value Proposition"

Another important factor to be aware of when discussing the diffusion of a new technology, such as algae-based biodiesel, is an innovation's "value proposition." In other words, what value is the new technology bringing to the marketplace that doesn't already exist there today? A classic example is the mobile phone in comparison to a traditional land-line phone. While the cost of the latter is generally lower and its performance more reliable than a cell phone, it doesn't allow a consumer to "talk on the go." The "mobility value proposition" has enabled the market share of mobile phones to increase significantly in the past decade.

In the case of algae for biodiesel production, the *National Algal Biofuels Technology Roadmap* (hereafter referred to as the National Algae Roadmap) identifies a set of attributes that represent the value proposition of algal feedstocks in comparison to other biomass feedstocks (DOE, 2010, p. 3):

- Algal productivity can offer high biomass yields per acre of cultivation.
- Algae cultivation strategies can minimize or avoid competition with arable land and nutrients used for conventional agriculture.
- Algae can utilize waste water, produced water, and saline water, thereby reducing competition for limited freshwater supplies.
- Algae can recycle carbon from CO2-rich flue emissions from stationary sources, including power plants and other industrial emitters.
- Algal biomass is compatible with the integrated biorefinery vision of producing a variety of fuels and valuable co-products.

In addition to these attributes, algae-based biodiesel provides a number of consumer advantages that will enable it to compete with petrodiesel if the cost of the former can be brought more in line with conventional diesel, most importantly: algae can be grown domestically, thereby increasing our national security and contributing to local economic growth. The national security attribute of biodiesel fuels such as algae was a key factor behind the Navy's mandate that all its aircraft and ships be powered by a 50-50 bio/petrol blend by 2020 (Pernick et al., 2011, p. 13).

1.5 Science and Technology Challenges

The general view of sources consulted for this Report is that algae-based renewable energy has a great potential to be a source for biodiesel in the United States, but the S&T is still in its infancy, and significant advances need to be made through research, development, and demonstration (RD&D) activities before it is ready for large-scale diffusion in the liquid fuels market. For instance, a report recently completed by the Department of Energy (DOE), which analyzed the potential of microalgae as a feedstock for biofuels, concluded that it has the potential to be a "viable feedstock in the long-term, though algal biofuel technologies are still in relatively early stages of development" (FY 2011 Congressional Budget Request, 2011, p. 120). This conclusion is in-line with findings in the National Algae Roadmap (DOE, 2010, p. 5), which was published last year, as well as a closeout report of DOE's Aquatic Species Program that was published over a decade ago (NREL, 1998).

The National Algae Roadmap provides a detailed review of the S&T challenges associated with algal biofuels. For the purposes of this Report, it is sufficient to mention that the S&T challenges fall into three main areas critical to the large-scale use of biodiesel in the transportation sector (1) feedstocks, (2) conversion, and (3) infrastructure. The sub-elements within each category and their S&T challenges are summarized in Table 1, which was developed for the National Algae Roadmap. Of these three areas, feedstocks accounting for the largest percentage of the production biodiesel production costs, with some studies putting the figure at 70 percent (for example, see Pahl,(2007-12-18). Biodiesel: Growing a New Energy Economy (pp 188−189). Chelsea Green Publishing. Kindle Edition).

Table 1. Algal Biofuels S&T Challenges
From the National Algae Roadmap, p. 6

OVERCOMING BARRIERS TO ALGAL BIOFUELS: TECHNOLOGY GOALS

	PROCESS STEP	R&D CHALLENGES
FEEDSTOCK	Algal Biology	• Sample strains from a wide variety of environments for maximum diversity • Develop small-scale, high-throughput screening technologies • Develop open-access database and collections of existing strains with detailed characterization • Investigate genetics and biochemical pathways for production of fuel precursors • Improve on strains for desired criteria by gene manipulation techniques or breeding
FEEDSTOCK	Algal Cultivation	• Investigate multiple approaches (i.e., open, closed, hybrid, and coastal/off-shore systems; phototrophic, heterotrophic, and mixotrophic growth) • Achieve robust and stable cultures at a commercial scale • Optimize system for algal productivity of fuel precursors (e.g., lipids) • Sustainably and cost-effectively manage the use of land, water, and nutrients • Identify and address environmental risks and impacts
FEEDSTOCK	Harvesting and Dewatering	• Investigate multiple harvesting approaches (e.g., sedimentation, flocculation, dissolved air floatation, filtration, centrifugation, and mechanized seaweed harvesting) • Minimize process energy intensity • Lower capital and operating costs • Assess each technology option in terms of overall system compatibility and sustainability
CONVERSION	Extraction and Fractionation	• Investigate multiple approaches (e.g., sonication, microwave, solvent systems, supercritical fluid, subcritical water, selective extraction, and secretion) • Achieve high yield of desired intermediates; preserve co-products • Minimize process energy intensity • Investigate recycling mechanisms to minimize waste • Address scaling challenges, such as operational temperature, pressure, carrying capacity, side reactions, and separations
CONVERSION	Fuel Conversion	• Investigate multiple approaches to liquid transportation fuels (e.g., direct fuel production, thermochemical/catalytic conversion, biochemical conversion, and anaerobic digestion) • Improve catalyst specificity, activity, and durability • Reduce contaminants and reaction inhibitors • Minimize process energy intensity and emissions over the life cycle • Achieve high conversion rates under scale-up conditions
CONVERSION	Co-products	• Identify and evaluate the co-production of value-added chemicals, energy, and materials from algal remnants (e.g., biogas, animal/fish feeds, fertilizers, industrial enzymes, bioplastics, and surfactants) • Optimize co-product extraction and recovery • Conduct market analyses, including quality and safety trials to meet applicable standards
INFRASTRUCTURE	Distribution and Utilization	• Characterize algal biomass, intermediates, biofuel, and bioproducts under different storage and transport scenarios for contamination, weather impacts, stability, and end-product variability • Optimize distribution for energy and costs in the context of facility siting • Comply with all regulatory and customer requirements for utilization (e.g., engine performance and material compatibility)
INFRASTRUCTURE	Resources and Siting	• Assess and characterize land, climate, water, energy, and nutrient resource requirements for siting of microalgae (heterotrophic & photoautotrophic) and macroalgae production systems • Integrate with wastewater treatment and/or CO_2 emitter industries (in the case of heterotrophic approach) • Address salt balance, energy balance, water & nutrient reuse, and thermal management

PURSUING STRATEGIC R&D: TECHNO-ECONOMIC MODELING AND ANALYSIS

Given the multiple technology and system options and their interdependency, an integrated techno-economic modeling and analysis spanning the entire algae to biofuels supply chain is crucial in guiding research efforts along select pathways that offer the most opportunity to practically enable a viable and sustainable algae-based biofuels and co-products industry.

6 1. Overview

The S&T challenges identified in the National Algae Roadmap, and other algae studies all focus on bringing down the cost of algae-based biodiesel to a price competitive with petrodiesel. The National Algae Roadmap concludes "[t]here are indications…that a combination of improved biological productivity and fully integrated production systems can bring the cost down to a point where algal biofuels can be competitive with petroleum at approximately $100 per barrel" (National Algae Roadmap, 2010, p. 104). This is a significant cost reduction from current estimates of biodiesel produced from algae.

Lundquist et al. (2010), for instance, analyzed five algae biofuel production cases, and found that the only economically viable cases were ones in which algae ponds could be used for wastewater treatment and oil was produced as a secondary product. In the cases where biodiesel production was the primary product, oil costs were from $240 to $330 per barrel (Lundquist et al. 2010). The Lundquist study concludes: "Even with low capital charges, it is not possible to produce microalgae biofuels cost-competitively with fossil fuels, or even with other biofuels, without major advances in technology" (Lundquist, 2010, pp., xi-xii). The study goes on to suggest that "the major area for long-term cost improvements is in biology: the goal being at least double biomass and oil productivity through strain selection and genetic modifications," (Lundquist, 2010, p. xii).[8] Beal et al. assessed a host of studies that estimated the cost of producing algal biodiesel and found the cost ranged from $39 to $209 per barrel across the studies (Beal et al. 2010, p. 38). The cost variation was explained by the variability in the cost methodologies and reporting inconsistency across the studies.

1.6 Market Challenges

A variety of market challenges await a new technology as it begins to diffuse into its target market, ranging from human capital challenges involving the installation, operation, and servicing of the innovation; to capital challenges related to funding a start-up company that will manufacture and market the innovation; to technology lock-in challenges that have essentially "institutionalized" the existing technology in the target market. In the case of algae-based biodiesel, two of the biggest market challenges are (1) the price of oil, and (2) the market success of biodiesel fuels.

Price of Oil

From 1950 to 1970, the price of oil was very constant, hovering around $20 per barrel. The OPEC Oil Embargo of 1973, ended the era of stable oil prices, and ushered in three decades of volatile oil prices, ranging from a low of $12.71 per barrel in 1998, to high of $86.69, just ten years later (See Figure 3). The lack of sustained "high oil prices" has made it difficult for the algae industry to attract and sustain the resources necessary to overcome the S&T challenges and significantly reduce the cost of algae-based biodiesel.

[8] The Close-Out Study comes to a similar conclusion for future algae research, see Page 21 of the report for more details.

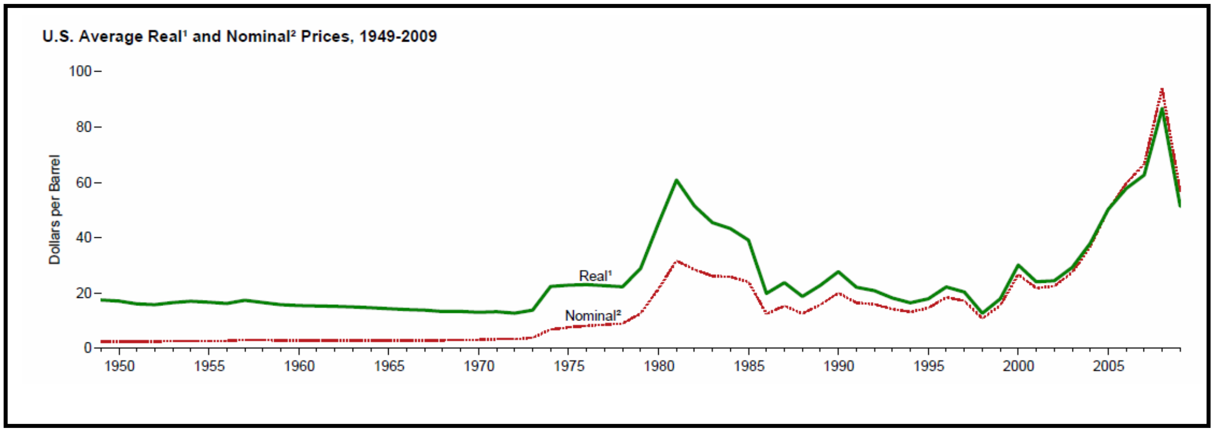

Figure 3. Crude Oil Domestic First Purchase Prices
From EIA Annual Energy Review, Figure 5.18 (2011a)

As a case in point, DOE's Aquatic Species Program, which sought to develop renewable transportation fuels from algae, began in 1978, when oil prices were at an all-time high, and ended in 1996, when prices seemed as if they were going to once again hover around the pre-OPEC Oil Embargo level. The Federal Government began investing in algae research again in the late 2000s, when oil prices were once again at historical highs. Market uncertainties about whether oil prices will remain high, or fall as they did in the 1990s, have discouraged the sustained, high-level private sector investment in algae-based biodiesel that is crucial for moving the technology from the laboratory to the marketplace.

In addition to market uncertainties impacting the supply-side of algal biodiesel, studies have found that oil prices significantly impact decisions being made by consumers on the demand-side of the equation. This impacts decisions by American consumers to purchase diesel vehicles that get more miles per gallon than conventional vehicles. For instance, David Diamond's (2009) analysis of electric-hybrid vehicles sales in U.S. states found a strong relationship existed between gasoline prices and the market penetration of electric-hybrid vehicles. In fact he notes: "The significance of state average gasoline price was expected, but the magnitude of its affect was much larger than anticipated" (Diamond, 2009, p. 982). In short, if oil prices remain low majority of American consumers will continue to do what they've being doing for decades—drive automobiles with gasoline powered internal combustion engines. If gasoline prices rise and continue to be high, this will motivate them to seek out AFVs that can reduce their transportation costs.

Given the importance of oil prices for the market penetration of alternative fuels and alternative fuel vehicles, the near- and mid-term trend will significantly impact the development and diffusion of algae-based biodiesel. The Energy Information Administration (EIA) forecasts that oil prices will be well-above historical levels in both its Reference Case and High Oil Price Case (see Figure 4). Even in the Low Oil Price Case, the cost of oil is likely to be double what it was in the pre-OPEC Oil Embargo Era. At the time of this writing, the crude oil futures price is $99.87 per barrel (EIA, 7/22/11), which suggests the Low Oil Price Case may be the least likely forecast to actually happen in the decades ahead. While this will pose many challenges for the U.S. economy as a whole due to its heavy reliance on petroleum-based products in the chemicals and transportation industries, it would be very favorable for the RD&D and commercial use of algae-based biodiesel because the price targets for making algal biodiesel cost competitive with petrodiesel will be closer to $100 per barrel, rather than the $20 per barrel.

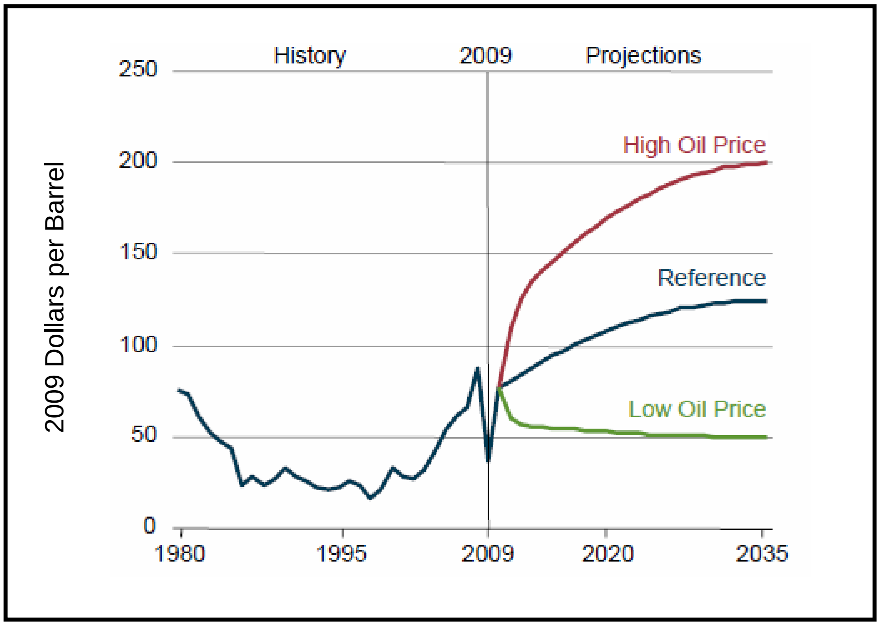

Figure 4. Average Annual World Oil Prices—Three Cases
From EIA Annual Energy Outlook, Figure 13 (2011b)

Pulling for the Market Success of Biodiesel Fuels

Technology lock-in can be a major market challenge for new innovations because the existing infrastructure and commercial products act as a barrier to the market penetration of technologies that cannot "piggy-back" on the conventional systems. In this respect, the future market success of algae-based biodiesel, will be closely tied to the consumption of "biodiesel fuels," in general.

Throughout most of the first decade of the 21st century, the outlook for biodiesel was very bright, with production increasing from about 1 million gallons in 2001, to 678 million gallons in 2008 (Schnepf, 2011, p. 17). However, in 2009 and 2010, the production of biodiesel dropped considerably, with total biodiesel production in 2010 being less than half of what is was in 2008 (see Figure 5). A variety of factors contributed to the decline in biodiesel production, including uncertainty about the renewal of the biodiesel tax credit; the high price of biodiesel feedstocks; and the Great Recession of 2008, which weakened demand for transportation fuel and led to a sharp decline in the price of diesel fuel (Schnepf, 2011). As Brent Yacobucci notes in his recent study of biodiesel fuel, its market success looks much less certain today than several years ago:

> Biodiesel production remains expensive relative to conventional petroleum-based diesel (even with tax credits), largely due to the reliance on soybean oil (a relatively expensive commodity) as a feedstock. Biodiesel and other [bio-based diesel] BBD fuel production remains dependent on both tax incentives and the [Renewable Fuel Standard] RFS mandates, as evidenced by a drop in production from 2009 to 2010. The expiration of the BBD tax credits after 2009 more than

counteracted the increase in the RFS mandate from 2009 to 2010. Whether enough biodiesel production capacity will come online in 2011 to meet an even larger mandate remains to be seen (2011: Summary Page).

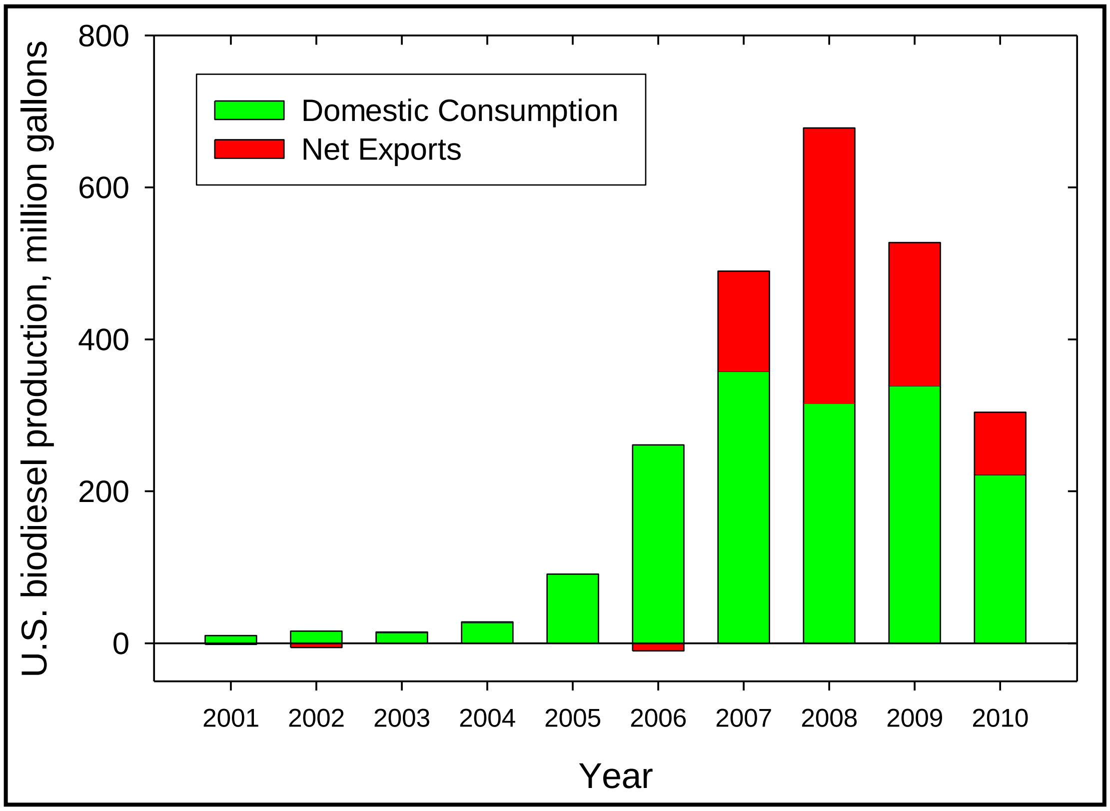

Figure 5. U.S. Annual Production of Biodiesel (Top of Bar), 2001 to 2010, Stratified by Domestic Consumption (Green) and Net Exports (Red)
Data from EIA Annual Energy Review (2010a)

While uncertainties about the market penetration of biodiesel will pose a challenge for the development of the algae fuels industry (1) mandates, (2) forecasts, and (3) anecdotal evidence provide reasons to be optimistic that biodiesel fuels will be available for algae-based biodiesel to piggy-back.

First, the RFS mandates that 1 billion gallons of biodiesel be produced by 2012, and algae-based biodiesel qualifies under this law. The growth rate of biodiesel production from 2000 to 2008, suggested this mandate would be easily met by the industry. However, the significant decline in biodiesel production in 2009 and 2010, will make meeting the 1 billion gallons target a challenge, but the target will still serve as a key driver for new biodiesel feedstocks such as algae.

Second, the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri published a biodiesel market outlook through 2020, which forecasts:

- Biodiesel production will increase to satisfy the RFS2 biomass-based diesel requirements and to help meet the RFS advanced biofuels requirements.

- In the out-years there will be modest increases in biodiesel exports, despite the EU tariffs, due to increased biodiesel prices in Europe.

And *Algae 2020*, which has tracked recent announcements in algae biodiesel to develop a rough-sketch scenario of growth in production of algal biofuel, forecasts production increasing from approximately 100,000 gallons in 2010 to over 6 billion gallons in 2025 (2011, p. 50).

Third, anecdotally, Solazyme recently delivered the largest shipment to date of algal aviation fuel—20,000 gallons—to the Navy (September 2010), and is contracted to produce 150,000 gallons for the Department of Defense in 2011 (Pernick et al. 2011, p. 12). The U.S. military is helping drive this demand for biodiesel by mandating that all Navy aircraft (and ships) be powered by a 50-50 bio/petrol blend by 2020. “As the largest fuel purchaser in the world, the Pentagon “will play an absolutely game-changing role in this space,” says Suzanne Hunt, senior advisor at the Carbon War Room, a Washington, D.C. group founded by Virgin chairman Richard Branson to support market-based emissions reduction (Pernick et al. 2011, p. 13).

1.7 Regulatory Challenges

The general view of sources consulted for this Report is that regulatory challenges are not a significant barrier to the development and diffusion of algae-based renewable energy at this time because the S&T that will eventually shape the algal biofuels industry is still in its infancy, and thus its development is not being hampered by a particular set of regulatory challenges that need to be resolved before algae-based renewable energy can diffuse on a large-scale in the liquid fuels market. This is not to say that the algae industry will not have to deal with the array state and Federal regulations in existence today. Rather, it suggests that the algae-based biodiesel industry does not face a competitive disadvantage due to regulations when it competes with other biodiesel fuel sources or the petrodiesel industry for market share.

In the previous section on Market Challenges it was noted that algal biodiesel can “piggy-back” on the biodiesel fuels penetrating the liquid fuels market today, which in the United States is currently dominated by biodiesel produced from soybean oil. The situation is similar on the regulatory front in that many of the key regulatory challenges facing algal biodiesel are the same challenges facing biodiesel fuels in general, particularly the uncertainties related to Federal biofuels regulations and incentives. In other respects, regulatory challenges such as prevailing petroleum-fuel standards” and the Environmental Protection Agency (EPA) regulations for combustion engine emissions serve as a target for the algae industry to work toward as it researches new algae strains. Each of these topics is discussed in more detail below.

Federal Policies Driving Biodiesel Production

Federal policy has played a key role in the market penetration of biodiesel in the U.S. liquid fuels market. Initially, Federal policy focused on tax incentives to make biodiesel more cost-competitive with petrodiesel. “The American Jobs Creation Act of 2004 (P.L. 108-357) created the first ever federal biodiesel tax incentive—a federal excise tax and income tax credit of $1.00 for every gallon of agri-biodiesel (i.e., virgin vegetable oil and animal fat) that is used in blending with petroleum diesel; and a 50 cents credit for every gallon of non-agri-biodiesel (i.e., recycled oils such as yellow grease)," (Schnepf, 2011, p. 16). Later, Federal policy focused on mandates to push biodiesel into the liquid fuels market. In 2007, the Energy Independence and Security Act (EISA, P.L. 110-140) expanded the RFS to include a mandate that a minimum volume of biodiesel be used in the national transportation fuel supply—500 million gallons in 2009, and growing to 1 billion gallons in 2012.[9]

Federal tax incentives like the biodiesel tax credit result in a cost to the Federal budget, and thus typically are in effect for less than five years. It is not uncommon for Congress to renew these incentives; however, the uncertainty that surrounds this process can hinder the growth of an infant industry as investors wait to see if Congress is going to renew the incentive before they invest. The biodiesel tax credit expired on December 31, 2009. Many in the industry expected it to be renewed; however, it was not renewed throughout most of 2010. "The biodiesel and ethanol tax credits, as well as the ethanol import tariff, were [eventually] extended through 2011, in last minute action (just prior to expiration of the ethanol credits) by the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010 (P.L. 111-312), which was signed into law on December 17, 2010" (Schnepf, 2011, p. 27). The law made the extension of these credits retroactive for all of 2010; however, the uncertainty that surrounded the extensions exerted downward pressure on the growth of the biodiesel industry, and "incentive uncertainty," is likely to continue to be a regulatory challenge for the biodiesel industry since the credit is set to expire at the end of 2011. In addition, the deficit concerns in Congress and the White House are likely to increase the scrutiny of renewing any incentive that has a high price tag for the American tax payer. Based on the assumptions of the RFS, the biofuels tax credits represents a total liability to the U.S. Treasury of about $200 billion from 2008 through 2022 (Schnepf and Yacobucci, 2010, p. 16).

Regulations Serving as a Guide for Algae RD&D

While existing regulations can pose performance challenges for new technologies, they can also help to guide the RD&D roadmaps by providing clear targets for these research efforts and facilitating the develop of industry-wide performance standards. Given algae-based biodiesel is a "nascent industry, there are no existing standards for various aspects of algal biofuels production;" thus, the regulatory challenge confronting the algal biofuels industry involves the "need to foresee and understand the potentially applicable legal requirements early on in the research and development process to help ensure algae are legally and safely developed, and the end-products (i.e., biofuels and co-products) comply with applicable standards" (DOE, 2010, p. 7).[10]

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[9] "EPA did not have rules in place to operate that portion of the RFS in 2009, the mandate took effect for the first time in 2010 under a special one-time arrangement whereby the biomass-based diesel RFS for 2009 was combined with the 2010 mandate (of 650 million gallons) into a single RFS of 1,150 million gallons for 2010. In 2011, the mandate returns to its original trajectory of 800 million gallons, rising to 1 billion gallons in 2012" (Schnepf, 2011, p. 17).

[10] See Rachel G. Lattimore's presentation, entitled "Bloomin' Government! Environmental Laws and Regulations" at http://www.nrel.gov/biomass/pdfs/lattimore.pdf for a high level review of the laws and regulations that the algae industry may have to deal with as it develops in the years ahead.

In the case of the European Union (EU), where the biodiesel industry is more established, and has a much larger share of the liquid fuels market than in the US, Pahl contends:

> [A] main force driving increased biodiesel in the EU is the Directive of Fuel Quality. The EU Directive on Fuel Quality (and a number of voluntary agreements under other programs) has resulted in significant advances in diesel engine technology that have improved energy efficiency and reduced emissions. These improvements require high standards for the fuel used by these engines and the new EU CEN (European Committee on Standardization) fuel standard EN 14214, developed in cooperation with automotive, oil, and biodiesel industries in the member nations, ensures biodiesel's continued consistent high quality (Pahl, 2007-12-18). Biodiesel: Growing a New Energy Economy (p 67). Chelsea Green Publishing. Kindle Edition.

The role of fuel quality standards in advancing biodiesel-related technologies in Europe highlights the point that regulations can play a positive role in the diffusion of an innovation when the industry is in its infancy because it helps standardize the products and processes involving the technology, which is critical if a new technology hopes to "cross the chasm," and be deployed on a large-scale in a mainstream market.

Section 2. Recommendations

2.1 Introduction

In February 2002, the Department of Energy (DOE) sponsored a workshop (hereafter referred to as the "DOE Innovation Workshop"), that was organized and implemented by Harvard University's Kennedy School of Government, and brought together innovation experts from around the country to provide insights into government policies to promote technology innovation in the energy sector. The insights, which were subsequently published in a report entitled *The Role of Government in Energy Technology Innovation: Insights for Government Policy in the Energy Sector* (Norberg-Bohm et al: 2002), were derived from a comparative analysis of the history of government involvement in four sectors—computers and electronics, agricultural biotechnology, industrial chemicals, and the power sector; as well as an analysis of government's role in defense and civilian technology innovation. The DOE Innovation Workshop concluded:

> First and foremost, government has an important role to play throughout the process of innovation—from invention through diffusion. During the period spanning pre-commercialization through lead adoption, for many energy sector technologies the government will need to employ both "supply-push," and "demand-pull" strategies. Supply-push policies stimulate investment in R&D for new technologies, and in addition to government sponsorship of R&D, include policies such as R&D tax credits. Demand-pull policies create markets for emerging technologies, and include a range of approaches such as regulatory standards, subsidies and taxes, and information-based approaches such as labeling. A second conclusion is that during the period spanning pre-commercialization through lead adoption, supply-push policies are best organized as public-private partnerships (Norberg-Bohm et al, 2002, p. 127).

> [In short, m]ultiple policies, working together in a synergistic package (italics added), were the key to successful technological innovation and particularly to the success of radical technological transformations in computers/electronics, agricultural biotechnology, and power sector technologies. This included policies that increased R&D (supply-push policies) as well as policies that supported the development of markets for emerging technologies (demand-pull policies). Multiple policies throughout the innovation process will be needed to support on-going technological innovation in the energy sector. The need for simultaneous supply-push and demand-pull policies is supported by the histories examined in this volume, as well as because of market failures throughout the innovation process in the energy sector (Norberg-Bohm et al, 2002, p. vii).

This section of the Algae-Based Renewable Energy in Missouri Report builds upon the workshop's conclusion that ***government's trying to stimulate energy innovation must advance multiple "push-pull" policies working together in a synergistic package***.

A multitude of state-level biodiesel policies currently exist in the United States, but this Report was unable to identify any that are specific to algae as an alternative feedstock for biodiesel (see Appendix B the instances in which algae is identified state biodiesel policies).[11] This is in keeping with this study's review of Executive Orders, and legislation in Missouri which did not find any policies specific to algae for biodiesel.[12] In general, the biodiesel policies on the books in Missouri and other states apply to algae, even though it is not called-out explicitly in the legislation. In most cases, the policies are a means to foster the use of biodiesel as an alternative fuel, such as biodiesel R&D support, or biofuels production grants. In several cases, the policies mandate the use of biodiesel fuel when it is available. This Report focuses on policies Missouri can advance today that are a ***means to a sustainable algae industry*** in the decades ahead. In brief, the Report recommends that Missouri:

- Build upon and enhance its existing biofuels RD&D capabilities to reduce the cost of algae biodiesel, and resolve other scientific and technical challenges critical to its successful diffusion in the liquid fuels market;
- Support the development of an algae techno-economic analysis capability to increase the knowledge pool that public and private decision-makers can draw upon when making choices involving the RD&D and diffusion of algae-based biodiesel in Missouri and other states in the country;
- Initiate an educational campaign to help Missouri's citizens better understand the *value proposition* of algae-based biodiesel;
- Serve as a catalyst for the development of an algae-based biodiesel network that will coordinate the technology push and market pull policies related to algae-based biodiesel.
- Design an algae-based biodiesel diffusion plan that systematically advances a set of demand-pull policies over the 2015 to 2025 timeframe.

These policies, if implemented as a synergistic package, will enable the State of Missouri to become a national leader in algae innovation.

2.2 Build Upon and Advance Missouri's RD&D Capabilities

The large-scale diffusion of algae-based biodiesel is at least a decade away because it is viewed as a third generation biodiesel feedstock by many experts.[13] Rather than simply "table" algae policies in Missouri until a low-cost form of algae-based biodiesel is discovered and demonstrated at a commercial scale, Missouri can begin to implement policies today that will enable it to become a national leader in algae RD&D. Task B documents the extensive RD&D capabilities that already exist in Missouri. While impressive, San Diego is the nation's algae

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[11] For instance, DOE's Alternative Fuels and Advanced Vehicles Data Center indicates that over 400 state-level biodiesel policies exist in the United States, and only five explicitly refer to algae.

[12] The review went back to the Year 2003.

[13] For example, see *Third Generation Biofuels from Microalgae* by Giuliano Dragone et al.

RD&D leader with "the Big 4 Algae Labs in San Diego representing nearly $1 billion in funding from private and public sector investment, representing the largest algae culture club in the world" (Lane, 2010). Missouri should set its sights on becoming recognized as leader in algae-related RD&D in United States. In order to do so, *the Missouri Government must invest in people and places to attract the world's leading algae researchers who will work in state-of-the-art algae RD&D facilities.* It can do so through a variety of policy mechanisms, from providing research grants or income tax incentives for algae-related RD&D, to encouraging state universities to create "algae research chairs" in their science and engineering departments.[14]

There are three major reasons to pursue this policy pathway:

- Public and private sector RD&D investments can be an economic engine for Missouri today, as evidenced by the $1 billion invested in San Diego, thus creating jobs and attracting more investment in the years ahead as more and more companies interested in algae-based biodiesel turn to the scientists and research facilities in Missouri to advance the RD&D of interest to them.
- The Missouri Government can support algae RD&D that leads to the creation, and/or development of algae species that are suitable for large-scale production in Missouri's terrain and climate, thereby enabling the State of Missouri to be a major producer of algae-based biodiesel when a low-cost species is discovered. The algae farms will create jobs in Missouri and enable a larger percentage of the State's petro-dollars to stay within its borders, thereby further stimulating the economy.
- The DOE Innovation Workshop found "policies that promoted competition, both inside and outside the normal sphere of technology policy, had enormous impacts on technological innovation and the commercial success in these sectors" (Norberg-Bohm et al. 2002, p.3). By actively working to become a national leader in algae RD&D, like San Diego is today, Missouri will play an important role in spurring algae RD&D competition in the United States which will help accelerate the development and diffusion of algae-based biodiesel in this country.

2.3 Support the Development of an Algae Techno-Economic Analysis Capability

In today's high-tech world, knowledge is king! As a recent story by Paul Voosen in Greenwire suggests, entrepreneurs who take a "great idea" to the marketplace before conducting a thorough techno-economic analysis can find themselves wishing they had done so as they watch their investments go bust.

> Few stories in the energy business are as seductive as that of algae biofuels. Using sunlight, CO_2 and little else, many varieties of fast-growing pond scum, when

[14] For a detailed analysis of government options for supporting R&D, see *Why and How Governments Support R&D* by Gordon Lenjosek and Mario Mansour and *The Government's Role in Promoting R&D* by Ben Bernanke.

> starved of nutrients, quickly build up oil in their cells. They need no external sugar from corn or cane to grow, so they don't compete with food crops. Farmed in ponds or translucent reactors, microalgae can be raised on cheap, sun-splashed land that is unsuitable for crops or much of anything else. That was the idea, anyway, of a host of startups that launched into algae fuels over the past half decade. Often ignorant of algae's biology, these companies stumbled into major physical and engineering hurdles that can derail most of their lofty goals, industry and government experts say. [For example,] [b]ioengineer Jeff Way has seen what happens when the claims of algae biofuel companies get ahead of the science, when their promises of "renewable diesel" slams into the realities of engineering. He's been to the bankruptcy auction. Once the standard-bearer for the algae revolution, GreenFuel Technologies failed almost two years ago. Spun out of the Massachusetts Institute of Technology, the company promised to convert waste carbon dioxide into fuel-producing algae. It opened a celebrated -- and, it turns out, expensive— pilot plant in Arizona. It raised more than $70 million in private funds. Then it went bust (*Greenwire*, 3/29/11).

As was noted in the Challenges Section of this Report, commercial innovation is a low percentage game with less than 2 percent of the ideas hatched in a laboratory making it into the marketplace. “Successful development of an algae-based biofuels and co-products industry requires the optimum combination of technical innovations in systems and processes, coupled with economic feasibility in the practical implementation and integrated scale-up for commercial production and marketing” (National Algae Roadmap, 2010, p. 93). *A robust techno-economic analysis capability is essential in this regard because credible data about the resource potential, technical potential, economic potential, and market potential of algae-based biodiesel in Missouri will be essential to motivate and convince investors and entrepreneurs to come to the state and make it the center of a national algae industry.*

NREL, in its study entitled *A Framework for State-Level Renewable Energy Market Potential Studies,* provides a useful structure for building an algae techno-economic analysis capability in Missouri by highlighting the interrelationship between technical and economic) components, as well as its resource and market potential.

> Figure [6] illustrates that market studies must build upon solid understanding of resource, [technical, and market] potential, because the resources vary by location and time, and their competitiveness varies by technology and market. Resource uncertainty, including climatic and weather system shifts and reallocation of land for alternative uses, can have a large impact on the economics and market situation for renewable energy. In the same vein, technology changes regarding performance (e.g., increased conversion efficiency) or cost (e.g., increased steel costs) can dramatically change the market impact that renewable energy can have. In short, renewable energy potential study types are interlinked and need to be used together to fully understand policy implications. (NREL, 2010, p.3).

The State of Missouri already poses some of the best techno-economic capabilities in the nation at its universities and private consulting companies (see Task B for more details on the existing capability). The Missouri State Government can help further develop these capabilities by investing in data-sets that provide unique and credible information about algae species, Missouri terrain, liquid fuel infrastructures and markets, and the innovation dynamics in Missouri. These data-sets can then be used by analysts in computer models that help inform decisions by investors, entrepreneurs, and policymakers that result in a sustainable algae industry in Missouri.

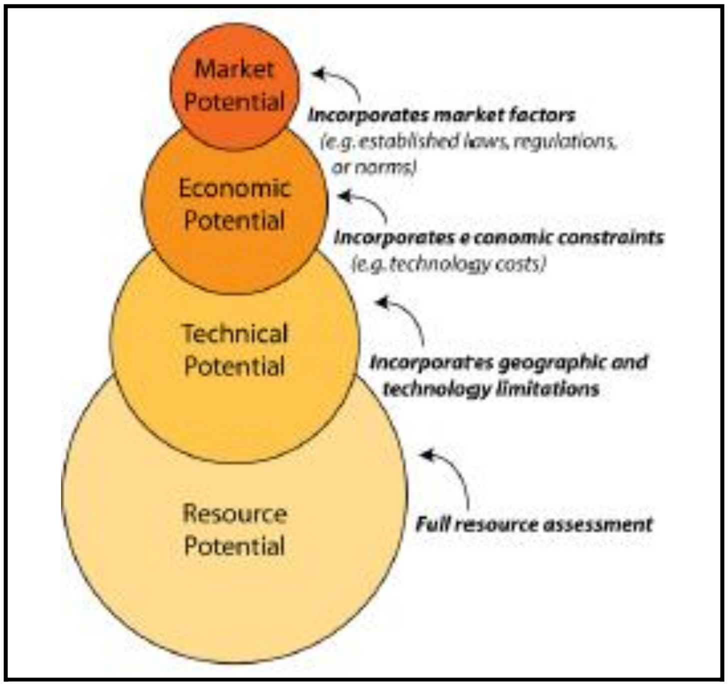

Figure 6. Types of Potential Innovation Studies
From NREL (2010)

2.4 Initiate an Algae Education Campaign

Misinformation can stop the diffusion of an innovation in its tracks. People generally associate "technology misinformation" with the myths and outright lies an innovation's detractors may be spreading about it. This type of misinformation has been an education challenge for the biodiesel industry as it has tried to increase consumer acceptance of biodiesel fuels by dispelling the myths that act as a barrier greater market penetration (see the biodiesel myths and facts box below for examples).

While myths and lies are one form of misinformation, it can emerge in other modes as well. For example, sometimes consumers are misinformed about a new technology because it is too closely associated with a technology that is very familiar, but has fallen out of favor in the marketplace. In the case of biodiesel fuels, some contend that the inclusion of the term "diesel," has hindered more than helped the fuels diffusion. Bob Clark,[15] for example, contends "We [i.e., the biodiesel industry], did ourselves a great disservice by ever calling biodiesel 'biodiesel'—we should have called it something else," he says. "The word diesel just has an unfair bad association in the minds of some people. The perception with the general public is negative, and it shouldn't be." (Quote from Pahl: (2007-12-18). Biodiesel: Growing a New Energy Economy (p 140). Chelsea Green Publishing. Kindle Edition). Studies on consumer preferences for diesel-fueled vehicles have found that American consumers developed a negative view of these

[15] At the time of this statement, Bob Clark was a sales manager of the biodiesel division of Imperial Western Products, Coachella, California. Pahl, Greg (2007). Biodiesel: Growing a New Energy Economy (Kindle Locations 105-106). Chelsea Green Publishing. Kindle Edition.

vehicles in the 1970s due to concerns about odor, engine noise, cold start problems, fuel availability, and reliability (Moore et al: 1998: p. 19). Even though a lot of these problems no longer plague diesel fuels and engines, these perceptions can serve to negatively brand any new fuel with the word "diesel" in its name.

A third type of misinformation is exaggerated claims about the innovation. Interestingly, these are often made by advocates of the innovation, and can be among the most damaging sources of misinformation. Peter Flynn, for instance observed:

> NGV [Natural Gas Vehicle] was hailed as being economical and more environmentally friendly than gasoline; in 1984, neither claim was true and each claim came back to haunt the industry… In hindsight, NGV would have had a more stable and sellable fuel if the proponents had been more honest: NGV had the potential to make a positive contribution to the environment, and realizing this potential would require permanent public subsidization. Exaggerated claims have damaged the credibility of alternate transportation fuels, and have retarded acceptance, especially by large commercial purchasers. It is particularly important that governments get clear messages about economics, so that stable public policy can be designed (2002, p 617–618).

Myths and Facts About Biodiesel Fuel

Several myths and facts about biodiesel fuel are rotating around the world. Biodiesel at present has been carefully and independently tested in almost every type of diesel engine. There are a number of agencies in the laboratory working more on the biodiesel fuel. Let us burst some of the common biodiesel fuel myths and facts in this article.

Some myths and facts on biodiesel fuel:

Biodiesel fuel myth: Biodiesel is still an experimental fuel and has not been tested thoroughly.
Biodiesel fuel fact: Biodiesel is one of the most thoroughly and methodically tested alternative fuels on the market. Research has shown that biodiesel performs comparably to petroleum diesel but with superior advantages to the environment and human health.

Biodiesel fuel myth: There are no objective standards existing for biodiesel fuel
Biodiesel fuel fact: Wrong. With the biodiesel industry active for more than 15 years, ASTM has set quality standards and specifications for biodiesel.

Biodiesel fuel myth: Biodiesel is inferior to diesel in performance
Biodiesel fuel fact: Biodiesel has a higher cetane number than diesel fuel and can be used in most existing diesel engines.

Biodiesel fuel myth: Biodiesel blends are incompatible with the new diesel engine
Biodiesel fuel fact: The fact is that the new engine emission control systems in the vehicles are all still easily attuned with blends up to at least B5. These rumors are baseless.

Biodiesel fuel myth: Biodiesel use annuls the manufacturers' engine warranty coverage.
Biodiesel fuel fact: All major automakers and engine manufacturers in the world accept the use of up to at least B5.

Biodiesel fuel myth: Biodiesel fuel has quality issues.
Biodiesel fuel fact: Study by the National Renewable Energy Laboratory (NREL) reveals that biodiesel industry has significantly met national fuel quality standards.

Biodiesel fuel myth: Biodiesel fails to work in cold weather.
Biodiesel fuel fact: Well managed, high quality biodiesel blends have been used successfully in very cold temperature.

Biodiesel fuel myth: Biodiesel fuel will lead to an increase in global warming because it meeds land to be cleared.
Biodiesel fuel fact: Using biodiesel decreases lifecycle carbon emissions by 60 to 80 percent, thus making it the best carbon reduction tool. There is no need for new cropland to make biodiesel as it is generally manufactured from co-products of crops already being grown.

Biodiesel fuel myth: Biodiesel fuel will contribute to rising food prices
Biodiesel fuel fact: As Biodiesel can be produced from a variety of renewable resources, like plant oils, fats, recycled grease, and even algae; it is the most diverse fuel on the planet.

Source: http://www.berkeleybiodiesel.org/an-overview-of-myths-and.html

In the case of algae-based biodiesel, some proponents of the technology are concerned that exaggerated claims about the oil yields of algae compared to other crops may end-up damaging the commercial prospects of algae-based biodiesel fuels. This point is highlighted in Paul Voosan's *Greenwire* article (3/29/11) which reads:

> And then there was "the chart." The most aggravating myth about algae, for Solazyme's Dillon and others, stems from a simple chart comparing the oil yields of common crops. One version was published by Yusuf Chisti, a biochemist in New Zealand, in 2007. It portrays algae, conservatively, as 130 times more productive than soybeans. Over the past five years, no other algae fuel paper has been as widely cited. It is the chart that launched a thousand overheated stories.
>
> "That chart perpetuates one of the biggest myths out there," Dillon said. "Everybody has seen versions of that chart. [But] I've never seen what I'd say to be proof that algae has even made as much oil as soybeans."
>
> There was a fundamental mistake people outside the algae business made when looking at the chart. They extrapolated speedy growth rates from open waters and ideal conditions to the industrial setting necessary for commercial cultivation, said Greg Stephanopoulos, a biochemical engineer at MIT and a longtime expert in bacterial manipulation. "They make fuels from free CO^2," Stephanopoulos said. "It's a no-brainer, right? They've got it all. So where's the problem? The problem is that you cannot cultivate [algae] at high enough densities to make this a worthwhile process."
>
> For every gallon of oil made from algae in a pond, hundreds of gallons of water need to be circulated, he said. The algae cannot grow in dense concentrations, because they do an excellent job of blocking sunlight, even when they don't use it for energy, instead wasting it as heat. "The issue is not one of designing a better reactor," Stephanopoulos said. "That's not going to solve this problem. The issue is not of doing better molecular biology. Even if you make all the algal cell full of oil, still you're going to have a [low] concentration of oil."

Misinformation about algae-based biodiesel, whether it's from the fuel's proponents or opponents, can significantly hinder its diffusion in the liquid fuels market. *The Missouri State Government can help inform consumers about the facts related to algae-based biodiesel, and dispel some of the exaggerations, myths, and misinformation by launching a long-term public information campaign.* The "Algae Education Campaign" can take on a variety of forms depending on that status of algae RD&D, the campaign's funding level, and its outreach partners. A sample nine-step approach for developing and implementing an algae education campaign is presented in Appendix A.

2.5 Catalyst for Algae Biodiesel Network in Missouri

Networks play an important role in the diffusion of an innovation because they connect the elements of an innovation's value chain, thereby facilitating the flow of information and coordination across the chain. In the case of algae-based biodiesel there will be individuals focused on the selection of the site for growing the algae, while others may be more concerned about cultivating and harvesting the algae, and still others may be focused more on biodiesel production, distribution, or use (see Figure 7 below). To varying degrees, these individuals will be connected by the very fact that they are all focused on algae-based biodiesel. *In many respects, however, the value chain will not be connected throughout the system and trade groups and government organizations can serve as an important catalyst to link elements of the network.*

In many respects, the National Biodiesel Board (NBB) in Jefferson, MO is the network catalyst for the biodiesel industry as a whole.[16] Anyone with access to the Internet can go to NBB's website and retrieve information about the biodiesel market segments or find out where it can purchase biodiesel. Given its success and recognition, a sub-group could be created in the NBB to develop an interconnect network across the algae biodiesel value chain; however, its focus would be national, not simply the State of Missouri.

A "Missouri Algae Policy Entrepreneur," however, could act as the network catalyst in Missouri to bridge existing elements of the value chain and build new linkages to support and extend the diffusion of algae biodiesel into the liquid fuels market. Studies of successful renewable energy activities at the state level have found that "policy entrepreneurs" have been the catalysts that have driven the transition to renewable energy in various states (Rahm et al.: 2006, p. 1). Lambright et al. (2006, p. 29) define

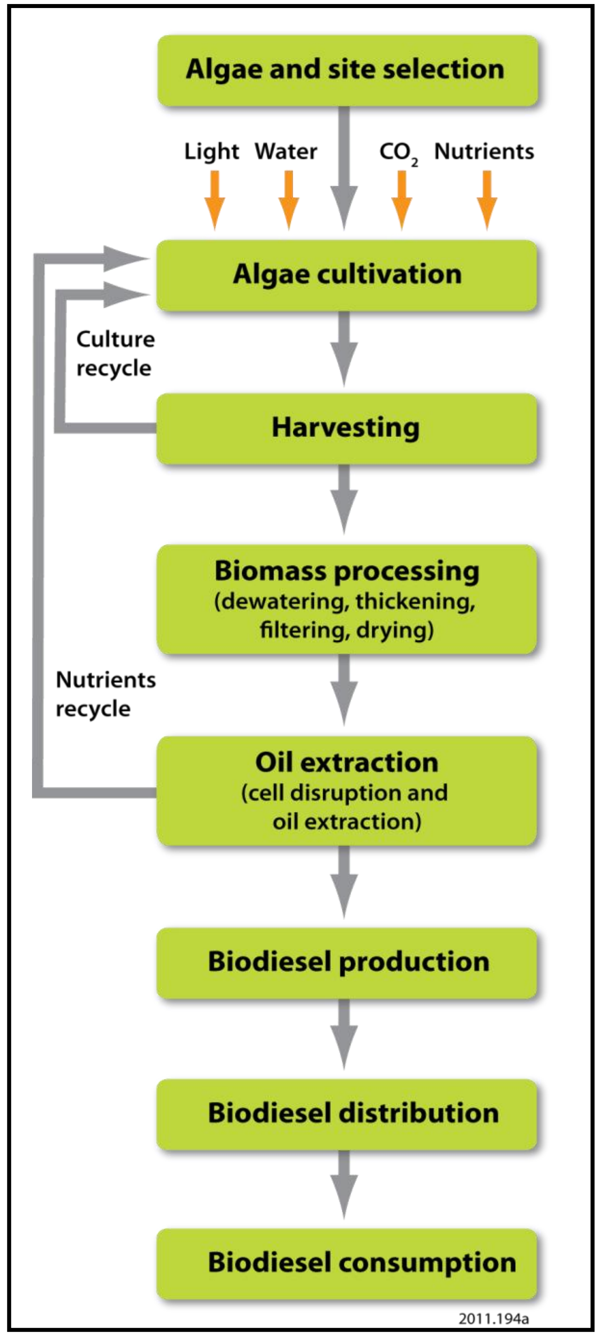

Figure 7. Microalgae Biodiesel Value Chain

[16] "The NBB is the national trade association representing the biodiesel industry as the coordinating body for research and development in the US. It was founded in 1992 by state soybean commodity groups, who were funding biodiesel research and development programs. Since that time, the NBB has developed into a comprehensive industry association, which coordinates and interacts with a broad range of cooperators including industry, government, and academia" (NBB Website - http://www.biodiesel.org).

policy entrepreneur as "someone who is willing to invest personal resources such as time, material resources and political capital into an issue." They write:

> As Kingdon (1984) notes in his study of agenda setting, policy entrepreneurs in and outside government play a large role in bringing attention to issues, in "coupling" policy problems with solutions, and in identifying and taking advantage of "windows of opportunity" to push policy proposals to the next stage of the policy process. In other words, policy entrepreneurs move the policy process along from one stage to another, often overcoming opposition or indifference of others. The actor that plays that role may change over time; in the agenda setting phase, an interest group might take the lead, while during implementation, a government bureaucrat might be the main entrepreneur. But unless some entity fills the role of policy entrepreneur, the policy often stalls at some stage of the process (Rahm et al., 2006, p. 29).

In other words, a policy entrepreneur is not a single individual or entity. Rather, it is a type of entity, be it public or private, that takes a lead role on the advancement of an innovation at a particular time in the innovation's research, development, demonstration, or diffusion to communicate across the network and coordinate the elements critical to the success related to the issues at hand; whether it be the passage of a bill to provide grant money for algae strain R&D, or coordination between the biodiesel producers, distributors, and users to help insure supply and demand forces remain in balance.

One sector of Missouri's economy that will be an important part of the "algae network" is the agricultural enterprise. Missouri is an agricultural state with lots of experience and capability in providing food, feed, and fiber for the citizen of Missouri as well as the United States at large. The advancement and widespread implementation of algae technologies in Missouri is most likely to be successful if a policy entrepreneur can get the agricultural enterprise in the state to accept algae as a crop and actively work to produce products from algae, such as biodiesel fuel. Further, algae is more likely to become cost competitive with petrodiesel if Missouri farmers are actively involved with its development and diffusion because they are more attune at keeping costs down than the industrial complex that generally operates at much larger economies of scale than farmers.

2.6 Long-Term Algae Demand Pull Plan

State Governments can impact the diffusion of new technologies through their purchasing power, public resources, and tax policies. The strategic use of these three "diffusion tools" can play an important role in helping the algae industry increase the market share of algae-based biodiesel in the State's liquid fuels market. Missouri already has a number of alternative fuel laws and incentive on the books that create a favorable environment for the commercial use of biodiesel fuels.[17] ***It is recommended that the State Government of Missouri continue to support***

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[17] For details on each MO law and incentive, go to http://www.afdc.energy.gov/afdc/laws/state_summary/MO. For information on biofuels policies in other states, see http://www.afdc.energy.gov/afdc/laws/state, and the Database for State Incentive for Renewables and Efficiency (DSIRE) at http://www.dsireusa.org/.

the implementation of alternative fuel laws and incentives that apply to algal biodiesel and create a "long-term algae demand pull plan" to help insure that the "proper set of policies are being advanced given the status of algae S&T. For example, a state law requiring five percent of all government vehicles use algal biodiesel would be "ahead of its time," if this fuel is not available at a volume necessary to meet the vehicles' fuel needs. Instead, the creation of a work group that looks at how best to move the algal biodiesel from the producers to the distributors when the fuel is ready for market may be a more strategic near-term algae policy for the state of Missouri. Each of the three tools mentioned above is discussed briefly below in the context of the liquid fuels market in Missouri.

Purchasing Power

The State Government of Missouri owns approximately 14,000 light-duty vehicles, consumes over 12,000 gallons of liquid fuel, and costs the citizens of Missouri about $25 million per year (Missouri Department of Natural Resources, 2010, Tables 1, 2, and 3). It currently has laws and incentives in effect to require a state agency that operates a vehicle fleet, consisting of 15 vehicles or more, ensure that at least 50 percent of new vehicles purchased are **capable** of using an alternative fuel, as well as plans to require at least 75 percent of the Missouri Department of Transportation (MoDOT) vehicle fleet, and heavy equipment that use diesel fuel, be fueled with biodiesel blends of at least 20 percent (B20)—**if such fuel is commercially available** (DOE Advanced Fuels & Advanced Vehicles Data Center). While these policies create a positive market pull for biodiesel fuels, they tend to favor biodiesel fuels available in the marketplace today, not new blends like algae-based biodiesel, that still have a technical risk for the consumer because they have not "proven themselves" commercially on a large-scale.

A multi-year algae-based biodiesel purchase contract between the State Government and a company producing liquid fuel with algae, can reduce market demand uncertainty associated with the fuel's technical risk, and help motivate a company to locate its production plant in Missouri. Purchase agreements can also play a key role in enabling the algae-based biodiesel production company to obtain financing at a lower interest rate than would be the case if it had to compete outright with other diesel fuels for sales in Missouri. The lower interest rates will allow the company to produce algae-based biodiesel at less cost, thereby enabling it to compete more effectively on a cost-basis with conventional fuels for non-government consumers of liquid fuels.

In addition to an algae biodiesel purchase agreement, a multi-year purchase agreement between the State Government and a select number of refueling facilities can help ensure that the means is available to distribute the algae-based biodiesel once it is produced.[18] A study by Peter Flynn (2002) on the lessons learned from the commercialization of natural gas vehicles (NGV) found that the lack of refueling stations played a key role in the limited consumer acceptance of compressed natural gas as an alternative transportation fuel in Canada in the mid-1980s. Flynn (2002, p. 615) found "[t]he failure to build profitability at existing stations in order to sustain investment in additional refueling facilities was, in hindsight, the most significant factor in limiting the growth of NGV." A purchase agreement between the Missouri State Government

[18] An income tax credit is available in Missouri for the cost of constructing a qualified alternative fueling station; for more details, see http://www.afdc.energy.gov/afdc/laws/law/MO/6450.

and a select number of filling stations can help ensure that the initial distributors of alga-based biodiesel receive enough business to be profitable, thereby helping sustain investment in additional stations, and ensure that the liquid fuels market share of algae-based fuels grows beyond State vehicles in Missouri.

Public Resources

The State Government owns land in Missouri and has the authority to set land tax policy throughout the State. The Lundquist study (2010, p. vi−vii) mentioned in the Challenges Section of this Report found that land is among the highest capital costs for algae biofuel production. The State Government can help reduce the cost of producing algae-based biodiesel by making a select portion of the State land available at no-cost to companies that agree to produce algae biodiesel in Missouri.[19] This policy option will help pull producers into the State because they can produce algae biodiesel at a lower cost, thereby increasing the fuels competitiveness with petrodiesel.

Tax Policies

“The market for biofuels has expanded rapidly since 2004, largely driven by federal policies, especially tax credits and a mandate for their use under the RFS (Congressional Research Service, 2011, Summary Page). Tax policies can be an effective tool for increasing the market pull of algae biofuel production in Missouri. All states impose some level of tax on gasoline and diesel fuel sales to raise revenue for a variety of purposes. For example, Missouri imposes a 17 cents per gallon tax on diesel fuel, which is slightly below the national average of 21 cents per gallon (source: http://www.missourigasprices.com/tax_info.aspx). Exempting algae-based biodiesel from this tax can help reduce the fuels cost, thereby making it more competitive with petrodiesel fuel in Missouri and helping pull algae into the liquid fuels market.

Missouri currently has an innovative tax incentive in place that compensates school districts who establish contracts with nonprofit, farmer-owned, new generation cooperatives, to purchase biodiesel blends of 20 percent (B20) or higher, for use in operating buses. In cases where there is an incremental cost to purchase the biodiesel, the school district is eligible to receive an additional payment through its state transportation aid payment (DOE Advanced Fuels & Advanced Vehicles Data Center). Amending this tax incentive to be specific to contracts between school districts and algal biodiesel producers, will help encourage these producers to locate in Missouri, because the tax incentive will enable their fuel to be more price-competitive with conventional options for the school district.

In addition to simply providing “algae-specific,” tax exemptions, or incentives, it is important for the State Government to stipulate a timeframe for the exemption and hold to it so algae biodiesel producers will know how long to factor the savings into their business plans. Uncertainty about the duration of fuel tax exemptions and incentives may discourage companies producing biodiesel in Missouri because they are concerned the policy will end before algae-

[19] At the moment, the closest policy to this recommendation is a biodiesel production incentive if the feedstock is frown in Missouri; for more information see http://www.afdc.energy.gov/afdc/laws/law/MO/5440.

based biodiesel is able to compete with petrodiesel on price-alone. Interestingly, Flynn found this to be the case with the commercialization of NGV in that “the industry was haunted with the prospect that once the fuel became widely used the foregone tax would be too substantial to ignore; in effect, success would kill the economic benefit of using NGV” (Flynn, 202, p. 617).

2.7 Conclusion

The S&T, market, and regulatory challenges associated with algae-based biodiesel suggest it is unlikely that algal biodiesel will significantly penetrate the liquid fuels market in Missouri within the next decade. While the algae industry is likely to remain in its infancy for this period, there are a number of strategic policy initiatives Missouri can pursue to help ensure it is a key player in the industry’s maturation, as well as enable Missouri to benefit economically when low-cost algal biodiesel is a mainstream commodity in the liquid fuels market.

In summary, this Report recommends that Missouri:

- Build upon, and enhance its existing biofuels RD&D capabilities, to reduce the cost of algae biodiesel, and resolve other scientific and technical challenges critical to its successful diffusion in the liquid fuels market.
- Support the development of an algae techno-economic analysis capability, to increase the knowledge pool that public and private decision can draw upon, when making decisions involving the RD&D and diffusion of algae-based biodiesel in Missouri and other states in the country.
- Initiate an educational campaign to help Missouri’s citizens better understand the *value proposition* of algae-based biodiesel.
- Serve as a catalyst for the development of an algae-based biodiesel network that will coordinate the technology push and market pull policies related to algae-based biodiesel.
- Design an algae-based biodiesel diffusion plan that systematically advances a set of demand-pull policies over the 2015 to 2025 timeframe.

These strategic policy initiatives will enable Missouri to stimulate the growth of the algae-based biodiesel industry through a set of multiple “push-pull” policies that work together in a synergistic package

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Section 4.
Appendix A. Nine-Step Approach for Implementing an Algae Education Campaign in Missouri[20]

Step 1: Assess the Current Outreach Situation

It is helpful to analyze what organizations have already attempted and achieved in terms of algae information dissemination before planning the "algae information campaign." What outreach efforts (activities, campaigns, and communication products) have been carried out so far?

- What audiences have been targeted by these efforts?
- What has worked?
- What has not worked?
- What partnerships have been created for these efforts?

Step 2: Identify Goals of a New Algae Education Campaign

Building on the lessons learned in the past (i.e., Step 1), the Missouri State Government should consider the following questions when identifying the goals of a new algae outreach campaign:

- What are the challenges that must be met with a new outreach campaign?
- How do these challenges relate to the broader goals of the Missouri State Government and partners in the education campaign?
- How best can the education campaign highlight algae's value proposition?

The answer to these questions can help select the challenges that should receive priority attention and funding. These priority challenges, in turn, will help define the goals for the new outreach campaign.

In expressing the goals of an outreach campaign, it is important to think in terms of a specific behavior that the campaign will seek to modify or encourage. Note that while educating and changing attitudes may play a role in eventually changing the target audience's behavior, the education and changes are not final aims in themselves.

[20] This nine-step approach is adapted from "public outreach campaign" information provided by the United Nations' World Intellectual Property Organization, and available at http://www.wipo.int/ip-outreach/en/tools/guides/planning/.

Step 3: Establish Clear Long-Term and Short-Term Objectives

Objectives can be expressed in terms of awareness raising/education in order to change the perceptions and attitudes of target audiences toward particular algae issues. These changes in perceptions and attitudes open the way for the ultimate goal of changing behavior as described above.

Such objectives could be wide ranging, for instance (1) to educate individuals about the distinctions between biodiesel and petrodiesel; (2) to help people understand how biodiesel fuel can be produced from algae; (3) to raise awareness about the potential economic impacts of a viable algae industry for Missouri; (4) to make people aware of the energy security and environmental benefits of algae-based biodiesel in comparison to traditional liquid fuels.

Step 4: Identify Target Groups

Different audiences have different wants and needs, so the algae education campaign will have to approach them in different ways. Target audience segmentation (the division of the general audience into smaller groups with similar wants and needs) is crucial to making sure that the right message will be sent to the right audience. Segmentation facilitates the process of tailoring messages and communication tools according to the needs and wants of the target audience.

In choosing among possible alternative target audiences, it helps to think about the behavior that will be promoted in the campaign, and the people that are most directly involved in, or affected by, that behavior. It may also be helpful to consider wider government policies (for example, a policy of assisting SMEs at different levels), or select the target audience based on its higher likelihood to respond positively to the behavior being proposed by the campaign.

Step 5: Identify Potential Partners

Partners are important in the development of outreach strategies because they can help reduce costs and increase impact. Each partner can bring a unique and valuable contribution (monetary, technical expertise, access to audience, etc.), to make the algae education campaign more effective.

Step 6: Develop Potential Messages

Information about target audiences is extremely helpful while brainstorming potential messages to communicate objectives. Solid information regarding the needs, desires, and current perceptions of the target audience facilitates the decision of what type of message to use in the communications program. Research has shown that target audiences respond better to messages that are:

- Clear and simple
- Personalized
- Communicated through various sources
- Consistent

Step 7: Choose Communication Media

There is a wide range of communication tools that can be used to deliver messages to target audiences. Choosing the right mix of communications tools will increase the chances of the message being noticed, retained, and thereby lead to the desired outcomes of the communications objective.

Step 8: Evaluate and Select the Best Message

Based on the list of potential messages developed in Step 6, and the decisions regarding style, tone, headline, argument and media, it is now time to select the messages that will be delivered in the algae education campaign to motivate certain behavior by various target groups. Small focus groups of the target audiences can be asked to evaluate each of the messages that make it to the final list to assist in the decision.

Step 9: Integrate all the Elements and Execute the Program

In order to ensure a consistent message and increase the chances of retention through effective repetition, all elements of the communication program (website, posters, advertisements, brochures, etc.), should have a similar "look." Working with its partners of the information campaign, the Missouri State Government should strategically implement the algae information campaign over a multi-year timeframe to help insure the algae advances are in line with the behavior being targeted in the information campaign. In other words, the "how to find a gas station that sells algae-based biodiesel," cannot be aired until the fuel is being produced and distributed at stations located throughout the State.

Section 5.
Appendix B. State Policies Specific to Algae-Based Biofuels[21]

Over 400 state policies exist that pertain to biodiesel fuels.[22] In many cases, the policies apply to algae-based biodiesel even though it is not explicitly called-out. Below are instances in which algae is included in the wording of the policy *(the term algae has been highlighted in each policy by the authors of this report*).

Alabama

Biofuel Production Facility Tax Credit

Companies that invest in the development of a biofuel production facility may be eligible for a tax credit of up to 5 percent of the capital costs of the project. Companies may claim this credit against the state income tax, or the financial institution excise tax liability that the project generates each year, for up to 20 years. For the purposes of the credit, biofuel is defined as a motor vehicle fuel that is produced from grain, starch, oilseeds, vegetable, algae, animal, or fish materials, including fats, greases and oils, sugarcane, sugar beets, sugar components, tobacco, potatoes, and lignocellulosic, or other biomass. To be eligible for the tax credit, the capital costs of the production facility must be at least $2,000,000, if the facility is not located in a favored geographic area, and $500,000, if the facility is located in a favored geographic area. A favored geographic area is defined as an area or county, that is designated as an enterprise zone, or that the Alabama Department of Industrial Relations considers to be less developed. (Reference Code of Alabama 40-9B-3, 40-18-190, 40-18-193, 40-18-194, and 40-18-202.1)

Connecticut

Biofuels Support

The Connecticut Department of Economic and Community Development (DECD) must administer a fuel diversification grant program to provide funding to Connecticut institutions of higher education or institutions of agricultural research for purposes including research to promote biofuel production from agricultural products, algae and waste grease, as well as biofuel quality testing. DECD must report on the performance of the grant program on an annual basis. (Reference Senate Bill 881, 2009, and Connecticut General Statutes 32-324g)

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[21] Source: DOE Alternative Fuels & Advanced Vehicles Data Center.
[22] Source: DOE Alternative Fuels & Advanced Vehicles Data Center.

Nevada

Alternative Fuel Study

The Nevada Legislature proposes to conduct an interim study concerning the production and use of energy in the state. The study will include the use and availability of transportation fuels and related facilities, including alternative fuels, and motor vehicle electrification, and a review of the extent and potential for biofuels production in Nevada including biodiesel, ethanol from nonfood sources, algae-based fuel, and other emerging fuel technologies. (Reference Senate Concurrent Resolution 19, 2009)

South Carolina

Biofuels Research and Development Tax Credit

For taxable years through 2011, an income tax credit is available for qualified research and development expenditures, which include developing feedstocks and production processes for cellulosic ethanol, and algae-derived and waste grease-derived biodiesel. Qualified expenditures involving cellulosic ethanol and algae-derived diesel are eligible for a 25 percent credit, and qualified expenditures involving waste grease-derived biodiesel are eligible for a 10 percent credit. Cellulosic ethanol is defined as fuel from ligno-cellulosic materials, including wood chips, corn stover, and switchgrass. (Reference House Bill 4478, 2010, and South Carolina Code of Laws 12-6-3631

Virginia

Biofuels Production Grants

The Biofuels Production Incentive Grant Program provides grants to producers of advanced biofuels, specifically fuels derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass or algae. A qualified advanced biofuels producer is eligible for a grant of $0.125 for each gallon of neat (100 percent) advanced biofuels sold. A qualified producer of non-advanced biofuels, including biodiesel, green diesel, and ethanol fuel, is eligible for a grant of $0.10 per gallon of neat biofuels sold in the commonwealth. To qualify, a producer must begin selling neat biofuels on or after January 1, 2008, and must produce at least one million gallons of neat biofuels before September 30, 2011. If a producer began selling neat biofuels before January 1, 2008, the producer is only eligible for a grant if its production of neat biofuels for the given calendar year exceeds its production in the 2007 calendar year by at least one million gallons and, in future years, continues to meet or exceed that amount. Each producer is only eligible for six calendar years of grants. This program expires June 30, 2017.
(Reference Senate Bill 1360, 2011, and Virginia Code 45.1-393 and 45.1-394)